

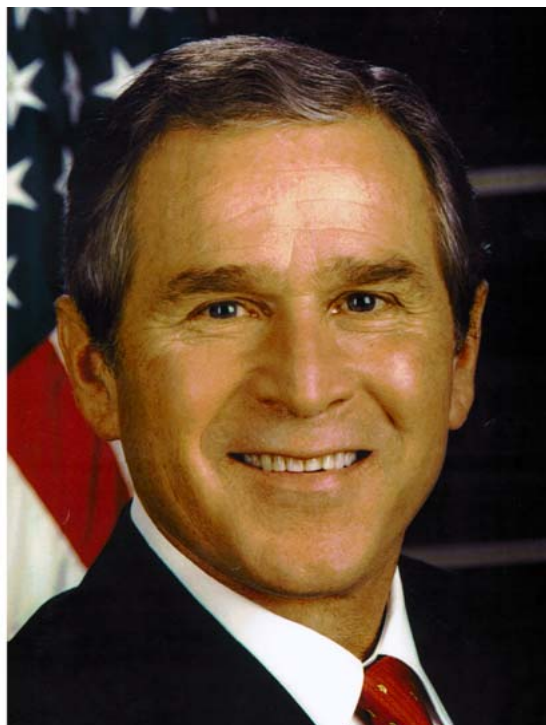
Why Ethanol from Cellulosics is Nearer Than You Think

**Professor Bruce E. Dale and Venkatesh Balan
Dept. of Chemical Engineering & Materials
Science**

**Michigan State University
www.everythingbiomass.org**

**Agri-Energy Conference
March 14, 2007**

Thank You Mr. President



Ethanol Production from Enzymatic Hydrolysates of AFEX-Treated Coastal Bermudagrass and Switchgrass

SULTAN RESHAMWALA,¹
BAHAA T. SHAWKY,² AND BRUCE E. DALE*¹

¹Department of Chemical Engineering, Texas A&M University,
College Station, TX 77843-3122; and ²Microbial Chemistry
Department, National Research Center, Cairo, Egypt

“...We'll also fund additional
research in cutting-edge
methods of **producing**
ethanol...from wood chips
and stalks, or **switch grass...**”

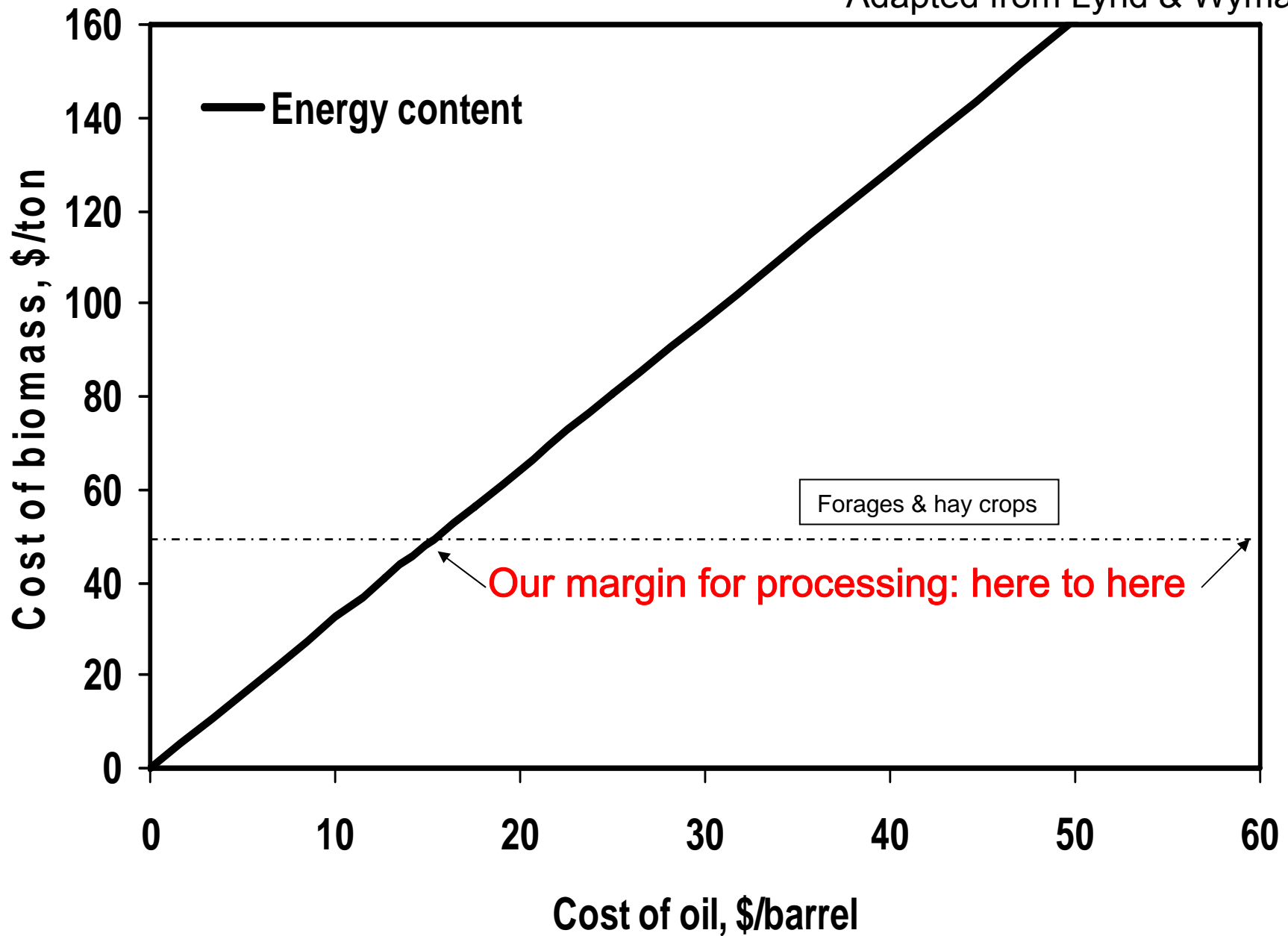
State of the Union Address, **2006**

Applied Biochemistry and
Biotechnology, Vol. 51/52

1995

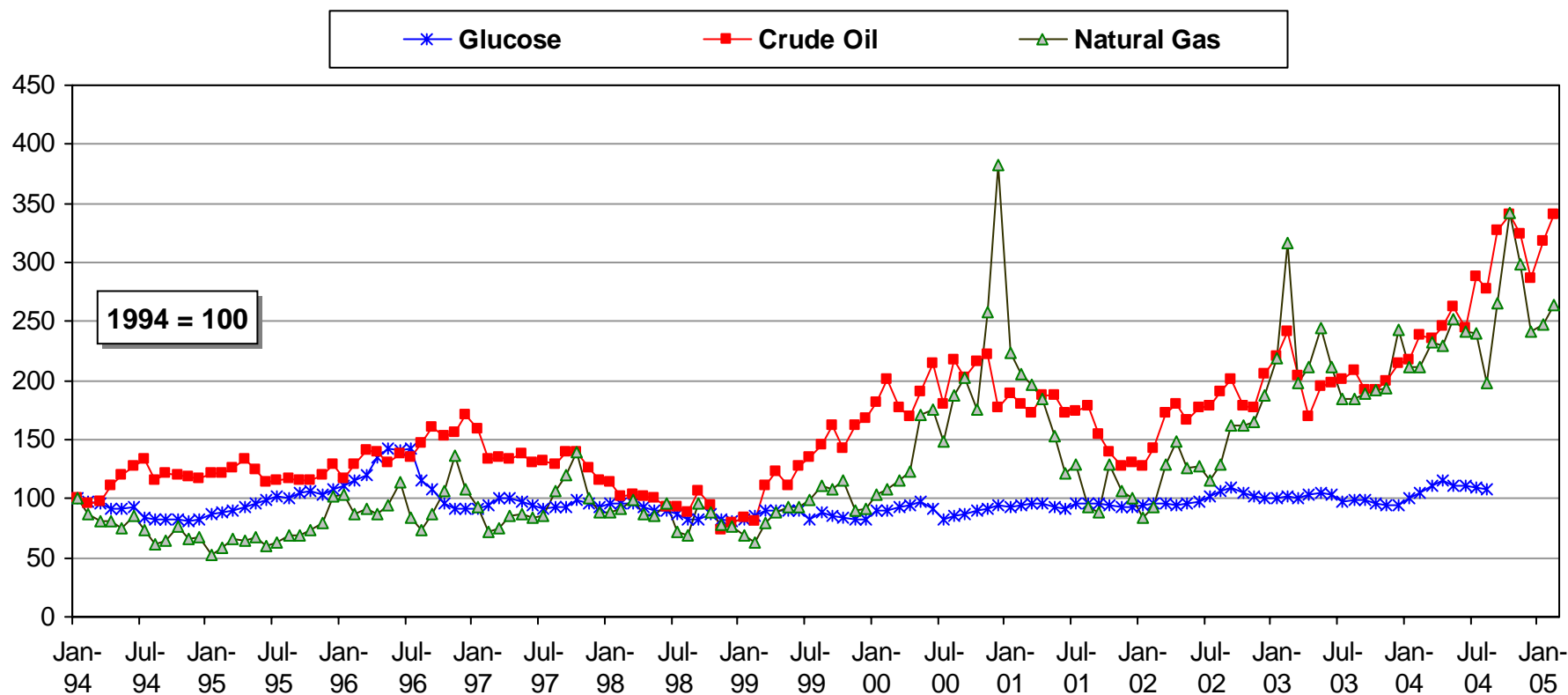
So It's Not Just About Politics

- Better Technologies
 - Better & cheaper pretreatments-AFEX for example
 - Better & cheaper enzymes
 - Better fermentation organisms
 - Consolidated bioprocessing (CBP) is progressing
 - Better integration of these technologies
- Venture capital & (we hope) more research funding
- Heightened awareness of oil “externalities”
 - Potential for climate change
 - Economic development driver
 - 9/11 and terrorism
- RFS & other help from our “big brother”: ethanol from corn
- Testing platforms: pulp mills & corn mills
- \$60 per barrel oil (or thereabouts)



Plant material is much, much cheaper than oil on both energy & mass basis

Glucose, Crude Oil & Natural Gas Price Index



Actual Jan 94

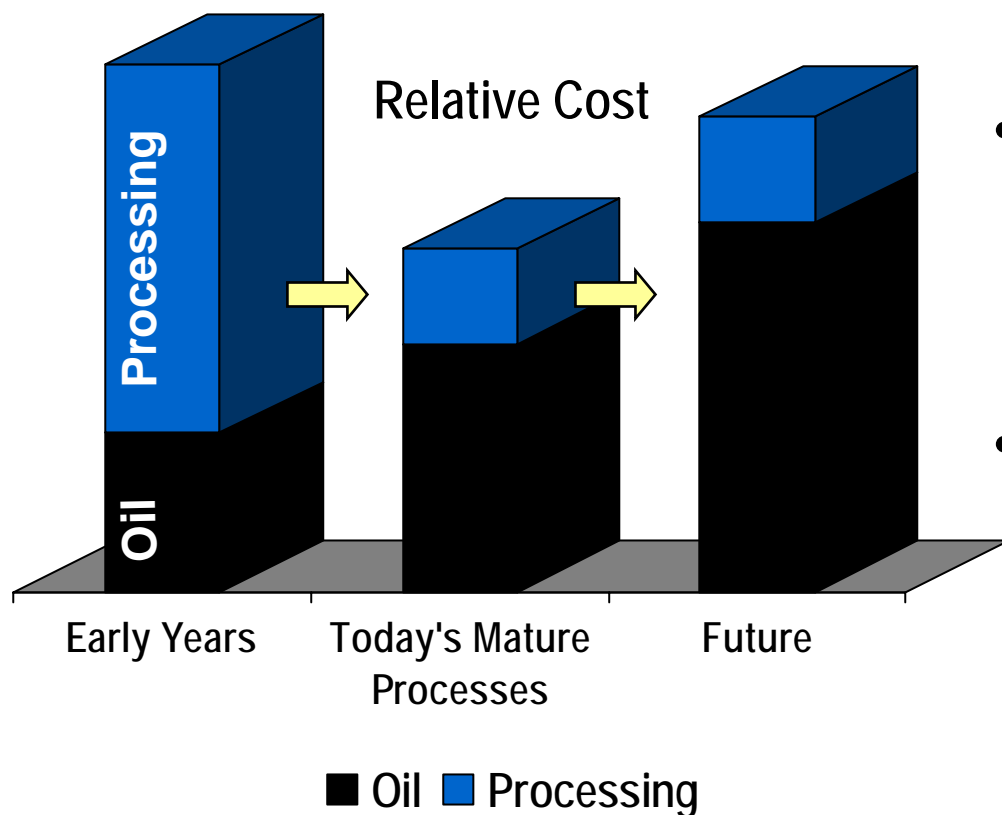
SBO (cents/lb)	28.93
Crude (\$/barrel)	15.19
Nat gas (\$/mm btu)	2.55
Propylene (¢/lb)	11.25

Actual Feb 05

SBO (cents/lb)	21.50
Crude (\$/barrel)	51.76
Nat gas (\$/mm btu)	8.73
Propylene (¢/lb)	43.00

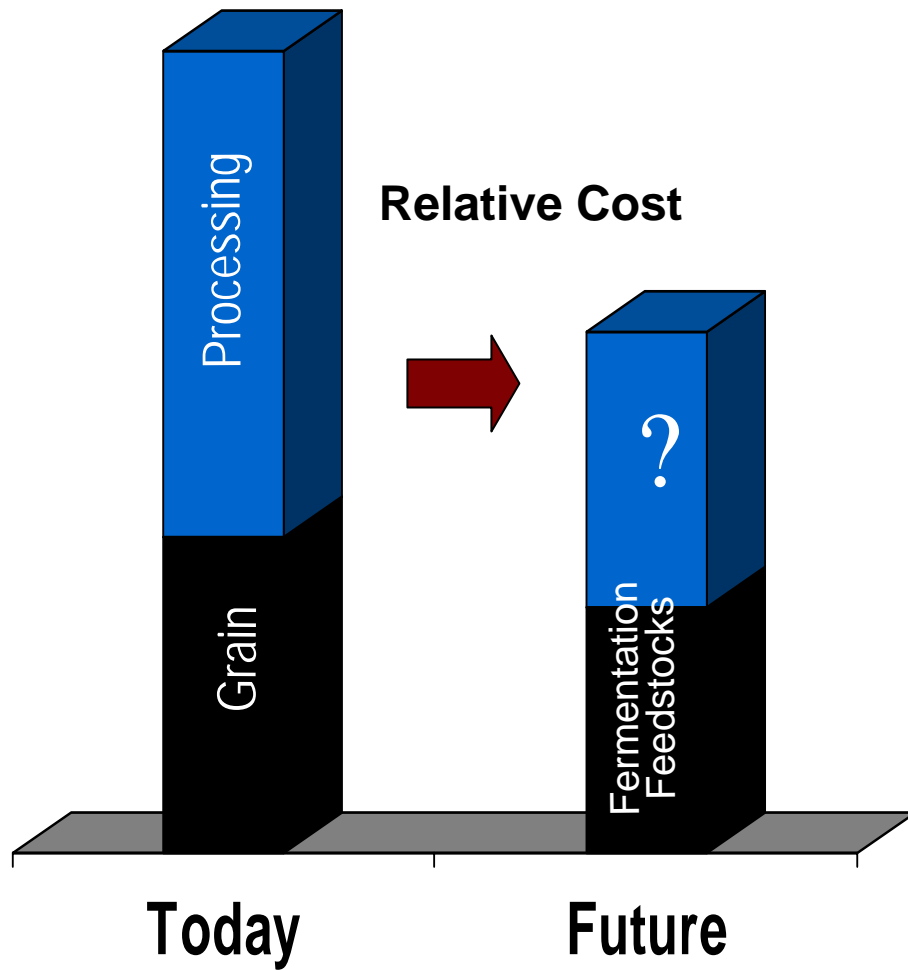
From J. Stoppert, 2005

Impact of Processing Improvements: Oil's Past & Future



- Historically, petrochemical processing costs exceeded feedstock costs
- Petroleum processing efficiencies have increased and costs have decreased dramatically but reaching point of diminishing returns
- Petroleum raw materials have long-term issues
 - Costs will continue to increase as supplies tighten
 - High price variability
 - Impacts national security
 - Climate security concerns
 - Not renewable
- **Not a pretty picture for our petroleum dependent society**

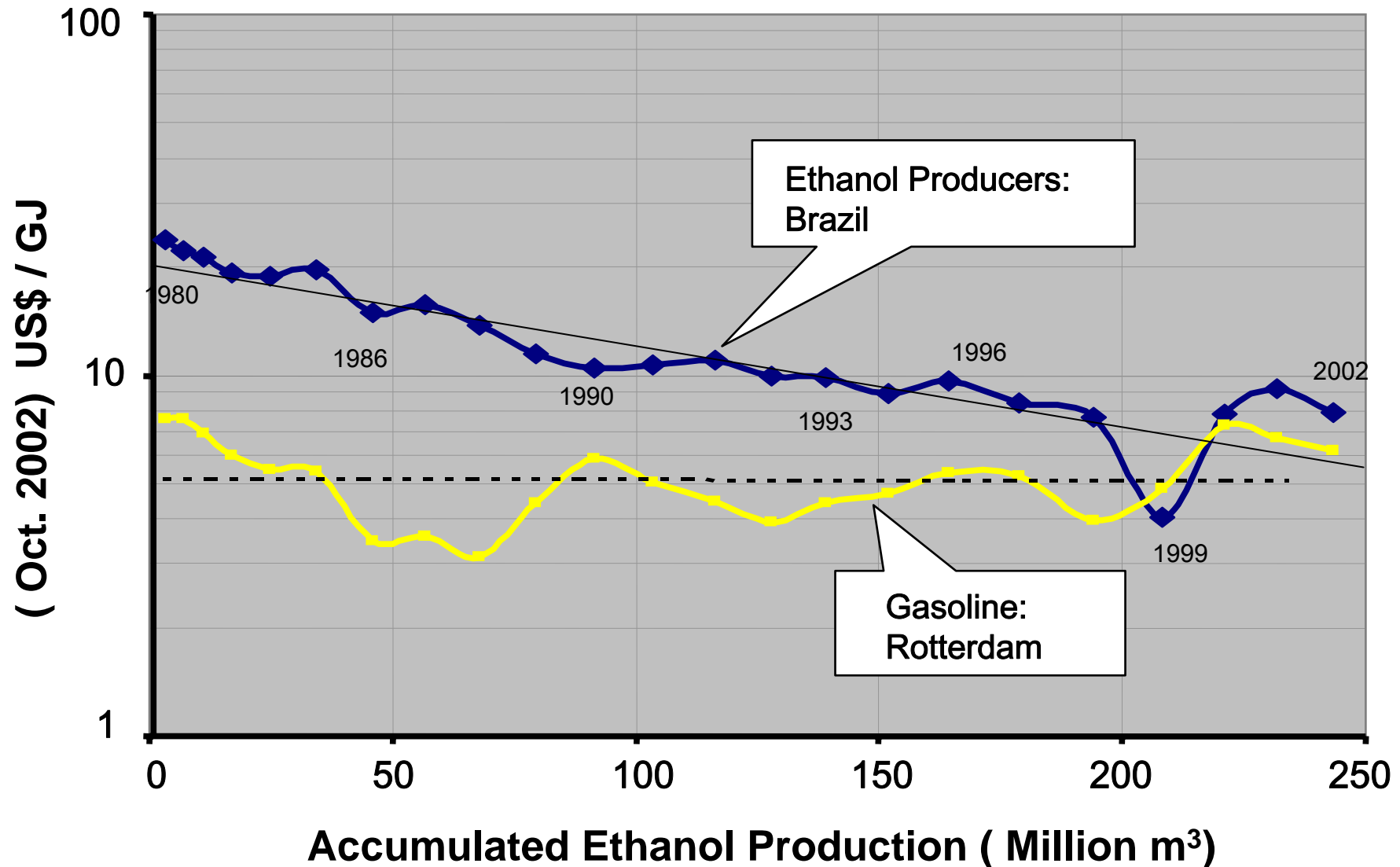
Impact of Processing Improvements: The Future of Biomass Conversion



- Processing is dominant cost of biofuels today
- Cellulosic raw material costs should be stable or decrease
- Processing costs dominated by pretreatment, enzymes & fermentation
- Biomass processing costs will decrease: deserves high priority to make it happen sooner rather than later
- **Much more attractive future**
 - Domestically produced fuels
 - Environmental improvements
 - Rural/regional economic development

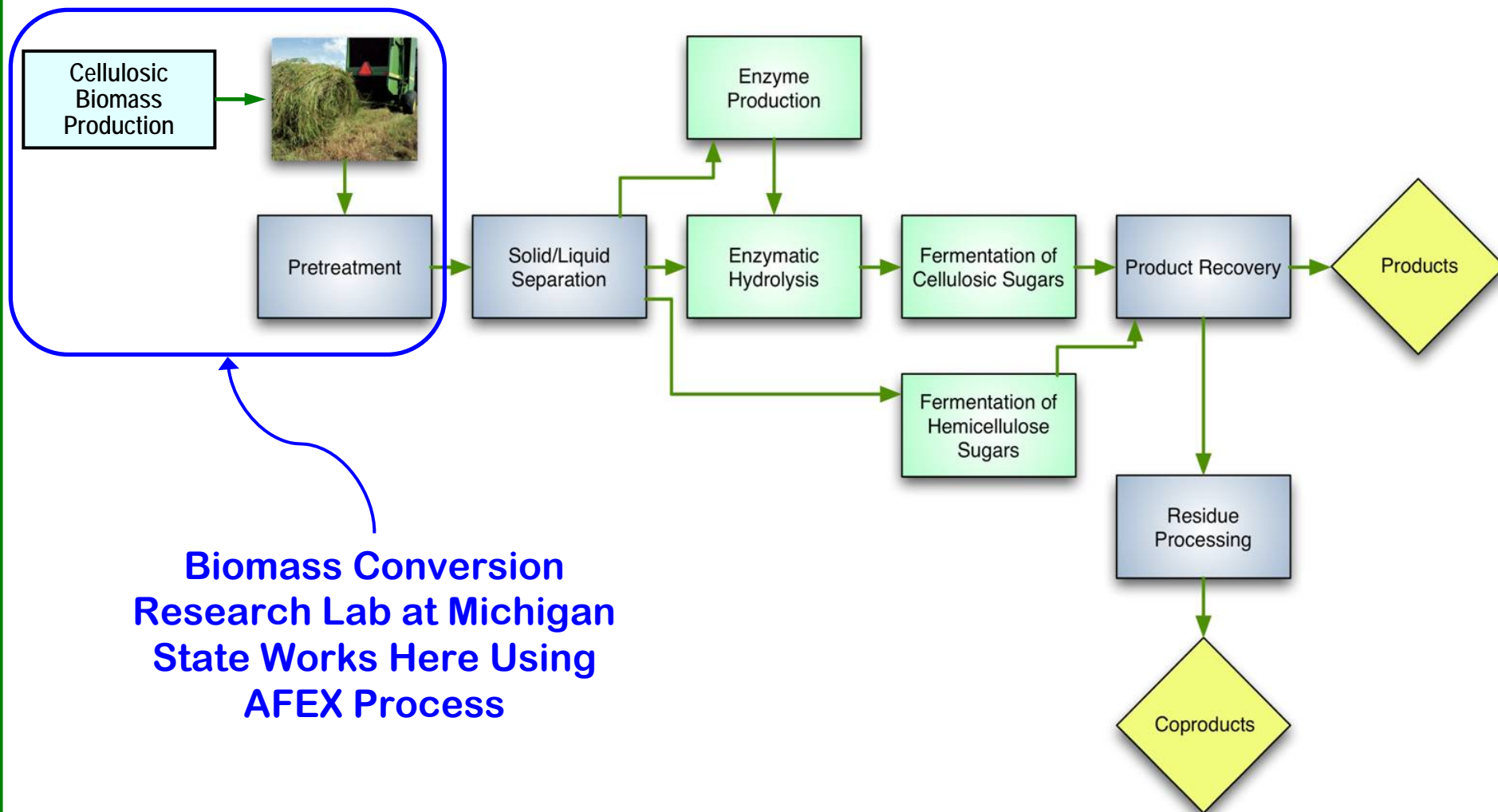
Learning Curve: Sugar Ethanol Production Cost

(J. Goldemberg, 2003)

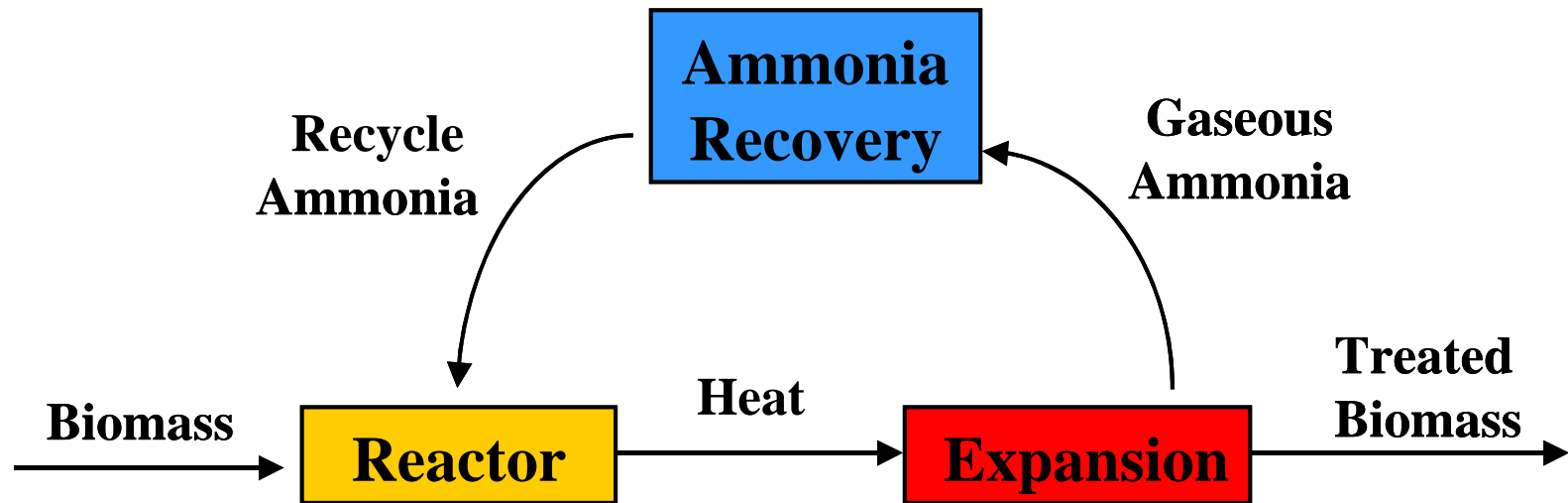


From a Techno Guy's Viewpoint

- Better technologies
 - Better & cheaper pretreatments
 - Ammonia fiber expansion (AFEX)
 - Better & cheaper enzymes-
 - AFEX with optimal enzyme mixtures
 - Better fermentation organisms
 - AFEX with engineered microbes
 - Consolidated bioprocessing (CBP)
 - AFEX with CBP
 - Better integration of these technologies
 - Cost reductions cascade with integration



How does AFEX work?

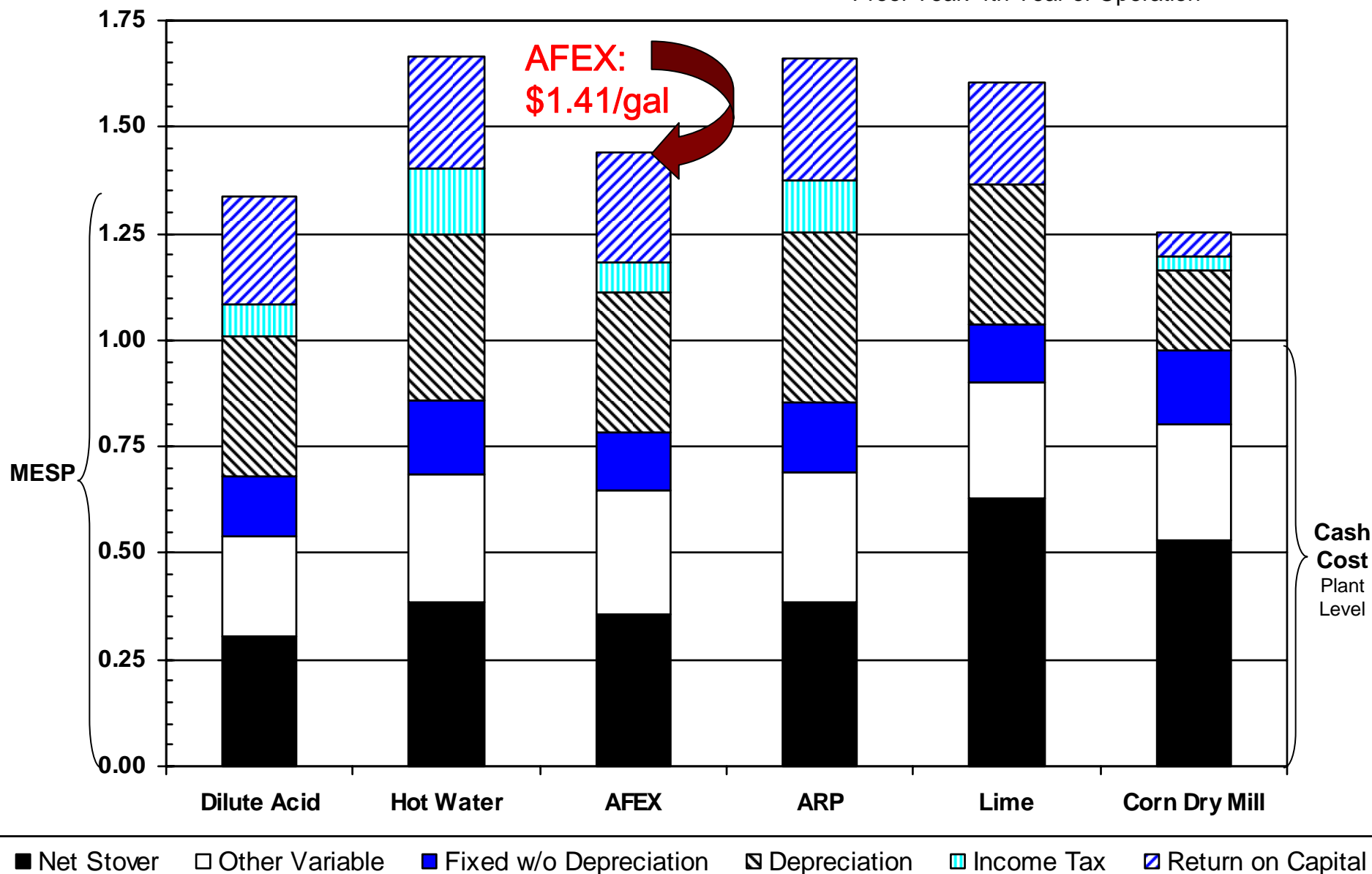


- Biomass heated (~100 C) with concentrated ammonia
- Rapid pressure release ends treatment
- 99% of ammonia is recovered & reused, remainder serves as N source downstream for fermentation
- Minimize sugar degradation, relatively mild conditions

Pretreatment Economic Analysis:CAFI Team

\$/gal EtOH

Proof Year: 4th Year of Operation



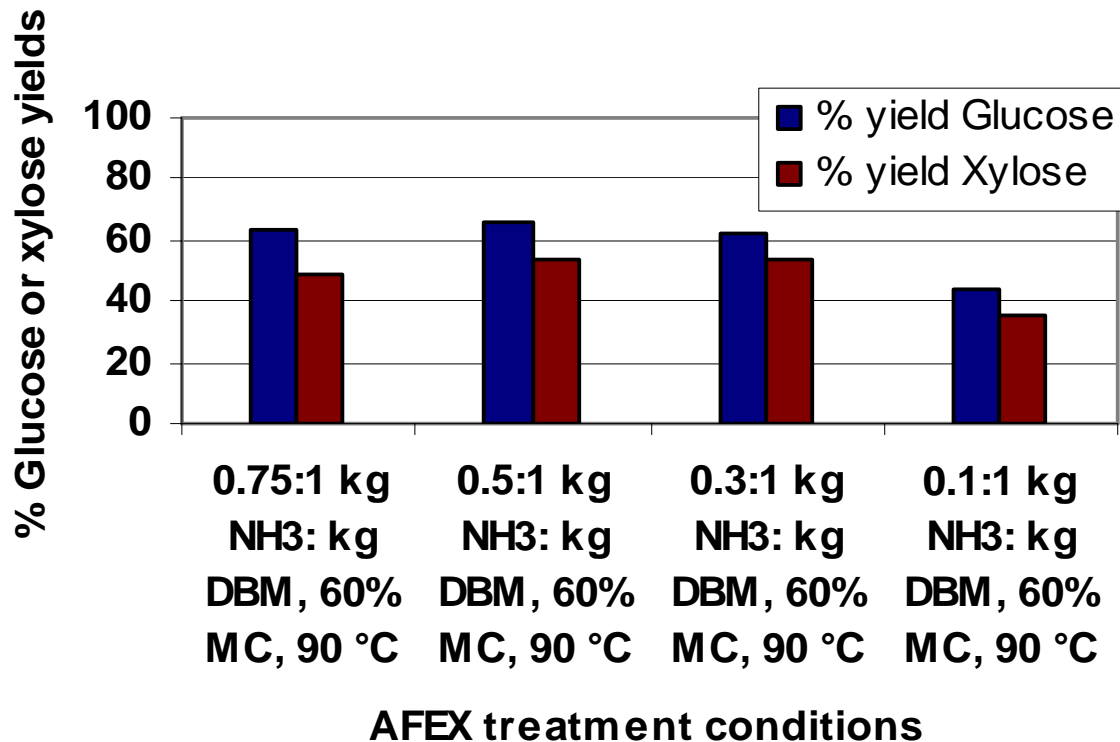
Results of CAFI Economic Analysis for AFEX*

- Reduce ammonia loadings
- Reduce required ammonia recycle concentrations (manage system water)
- Reduce capital cost of AFEX
- Reduce enzyme loadings for >90% conversion of glucan plus xylan

* *Our sincere thanks to Dr. Tim Eggeman:
NREL & Neoterics*

Reducing Ammonia Loading: 16 Hour Yields

**Key is to keep ammonia in liquid phase:
minimize ammonia vaporization**



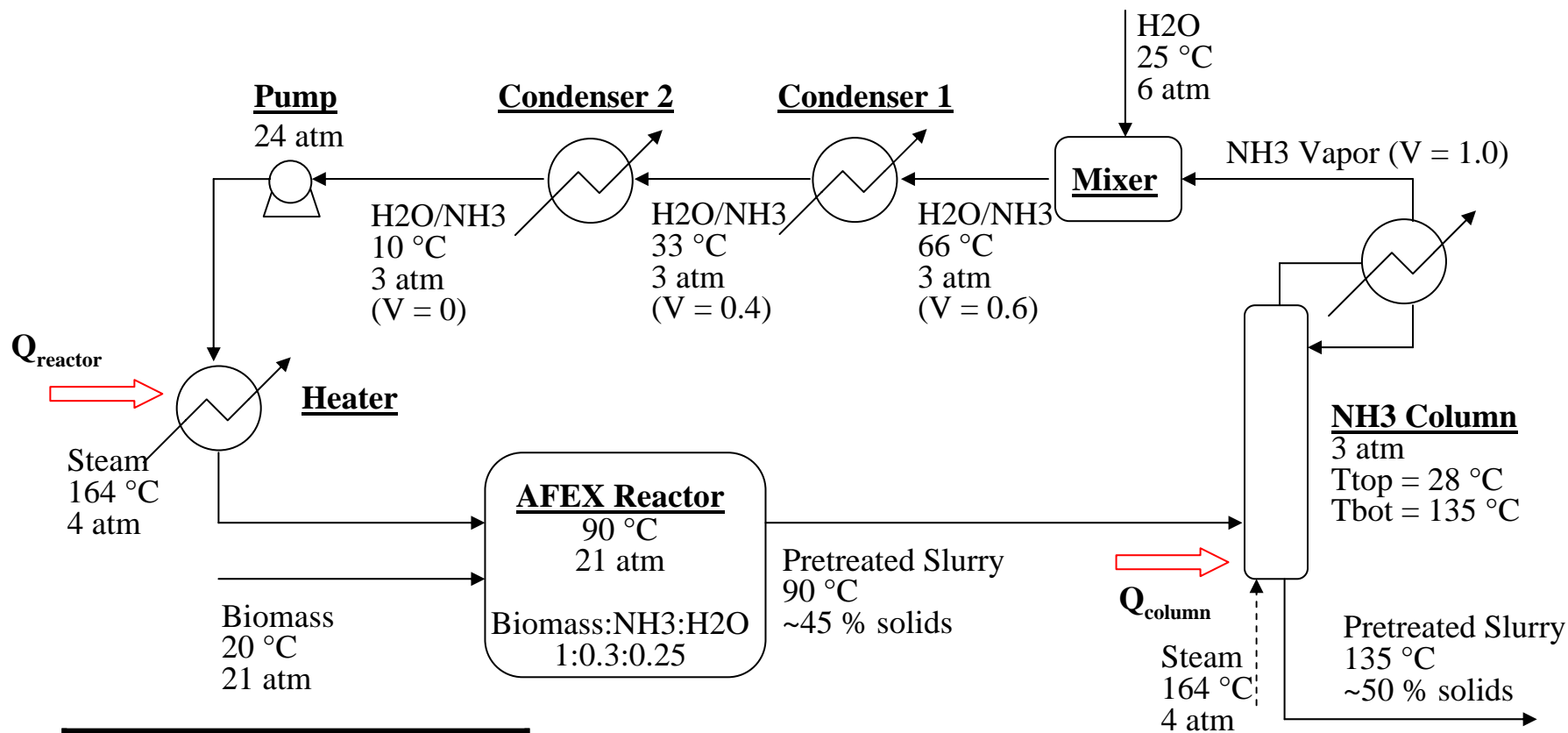
Managing Ammonia & Water in AFEX for High Sugar Yields

Ammonia Distribution	Water Distribution	% Sugar Yields G/X
All as NH ₃	All in stover	93.0/74.3
$\frac{3}{4}$ NH ₃ ; $\frac{1}{4}$ NH ₄ OH	$\frac{1}{2}$ NH ₄ OH; $\frac{1}{2}$ stover	93.0/78.9
“” “”	All in NH ₄ OH	79.9/64.9
$\frac{1}{2}$ NH ₃ ; $\frac{1}{2}$ NH ₄ OH	All in NH ₄ OH	57.7/47.9
“” “”	$\frac{1}{2}$ NH ₄ OH; $\frac{1}{2}$ stover	97.8/82.0
All NH ₄ OH	All NH ₄ OH	71.0/57.0
“” “”	$\frac{3}{4}$ NH ₄ OH; $\frac{1}{4}$ stover	97.1/79.0

Constant final conditions: 1 kg NH₃/kg dry stover,
60% moisture dwb, 90°C, 5 min.

Innovative Ammonia Recovery Approach

Slurry Distillation w/Quench Condensation NH₃ Recovery



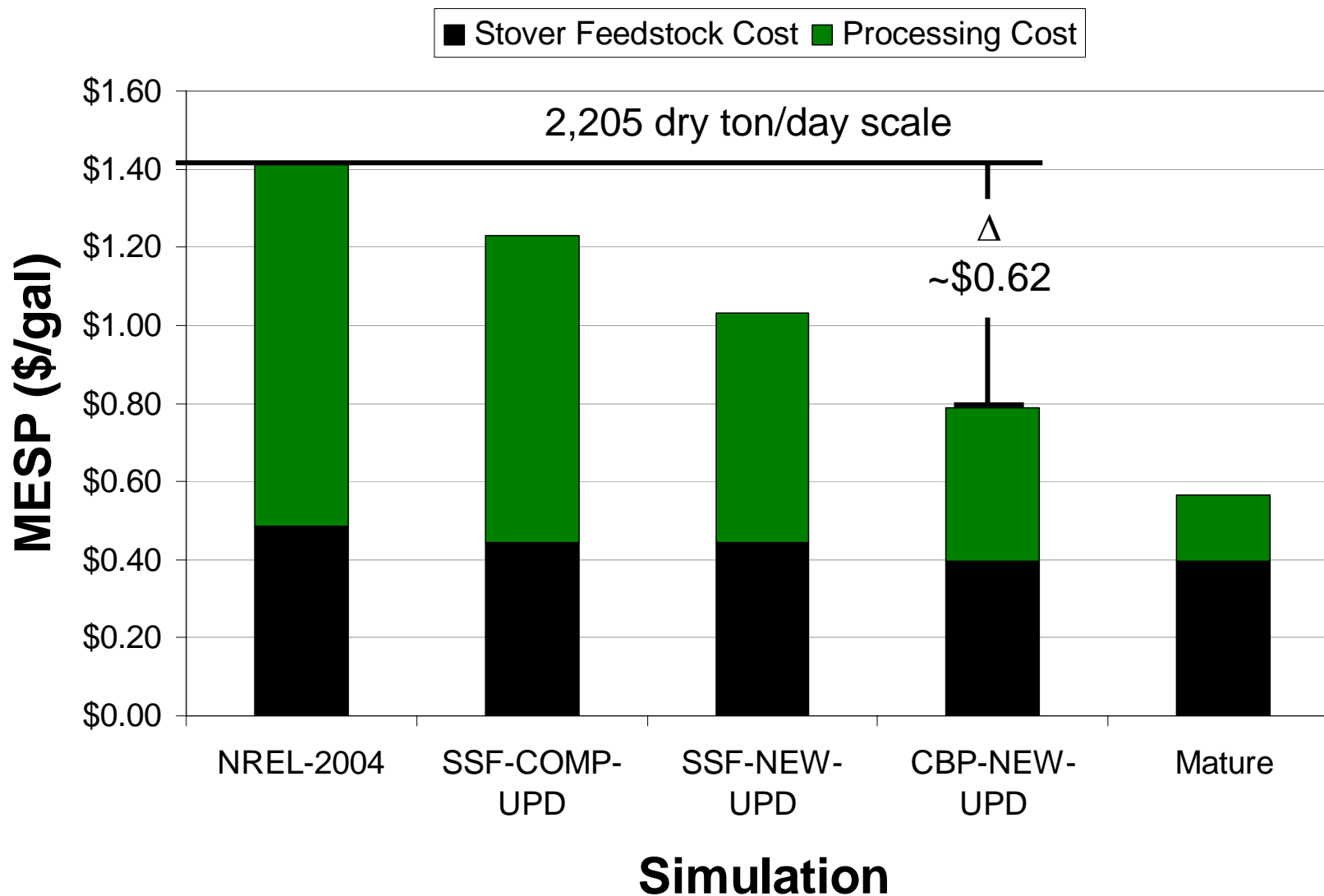
Energy Flow	(% feed LHV)
Q _{reactor}	0%
Q _{column}	2.6%
W _{chilled water}	0.3%
TOTAL	2.9%

Note: 3 atm (upper limit to keep T column < 140 °C at bottom)

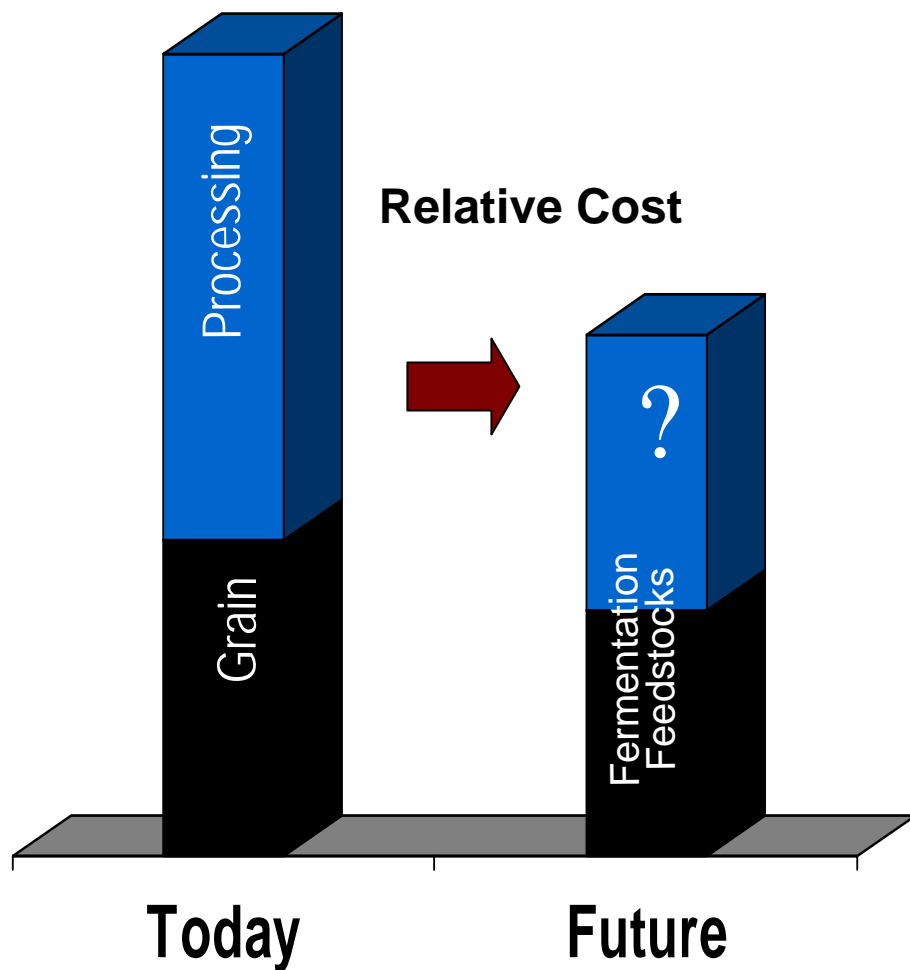
Effects of AFEX Process Improvements: New Cost Estimates (w/out Reduced Enzyme)

Abbreviation	Meaning
NREL-2004	SSCF, NH3 Recompression, Old AFEX parameters
SSF-COMP-UPD	SSCF, NH3 Recompression, Updated AFEX parameters
SSF-NEW-UPD	SSCF, New NH3 Recovery approach, Updated AFEX parameters
CBP-NEW-UPD	CBP, New NH3 Recovery approach, Updated AFEX parameters
Mature	Cost 70% Feedstock, 30% Processing

Final Results



Impact of Process Improvements: Cellulosic Ethanol is Nearer than You Think



- Processing is dominant cost of biofuels today
- Cellulosic raw material costs should be stable or even decrease long-term
 - Renewable resource
 - Potential for very large yield increases
- Biomass processing costs **will** decrease: Key question is *how far* and *how fast*
- *We need to get cellulosic ethanol out of the lab and into commercial operations*

Ethanol from Cellulosics: Look for Fast Growth!



courtesy Dr. Steve Long UICU

Capturing Local Benefits from Biofuels

- Some problems/issues:
 - Environmental benefits depend largely on local factors—requires local control & optimization
 - Cellulosic biomass is bulky, difficult to transport
 - Investment required for cellulosic ethanol biorefinery is huge ~ \$250 million and up—difficult for farmers to participate
 - Supply chain issues are also huge—need 5,000 ton/day from ~1,000 farmers: chemicals/fuels industries have **zero** experience with such large agricultural systems
 - Supply chains established for grains, not so much for grasses
 - Need to resolve “food vs. fuel”: actually “**feed** vs. fuel”
- Is there a common solution?
 - **Regional Biomass Processing Center— concept worthy of further study and development**
 - Pretreat biomass for biorefinery & ruminant animal feeding
 - Much lower capital requirements—accessible to rural interests
 - Potential to also accomodate high value uses: materials, nutraceuticals, enzymes, etc.

REGIONAL BIOMASS PROCESSING: SUPPLY CHAINS

**FARMS/
FORESTS**

**HIGH
VALUE
USES**

**ANIMAL
FEEDERS**

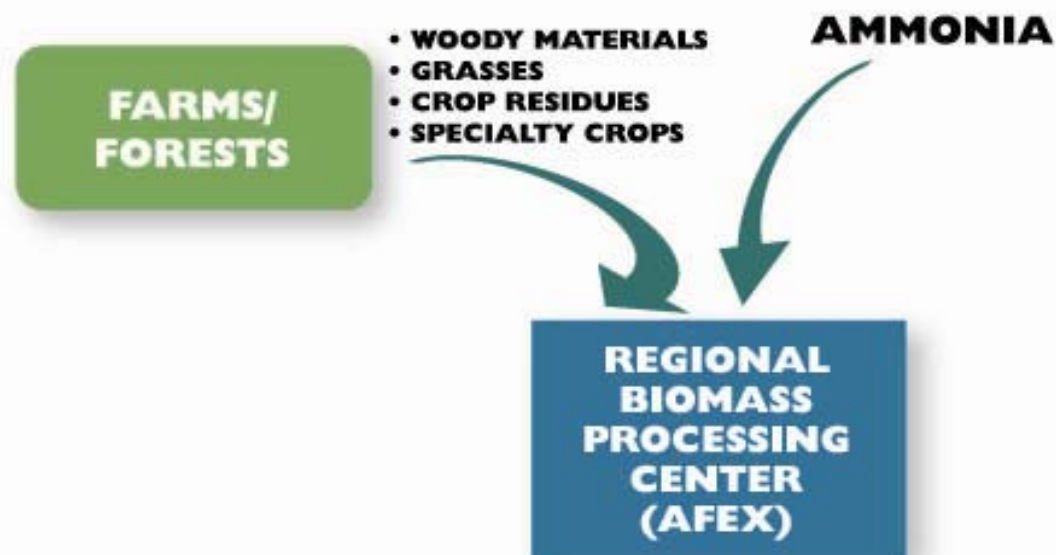
**REGIONAL
BIOMASS
PROCESSING
CENTER
(AFEX)**

**POWER
PLANT**

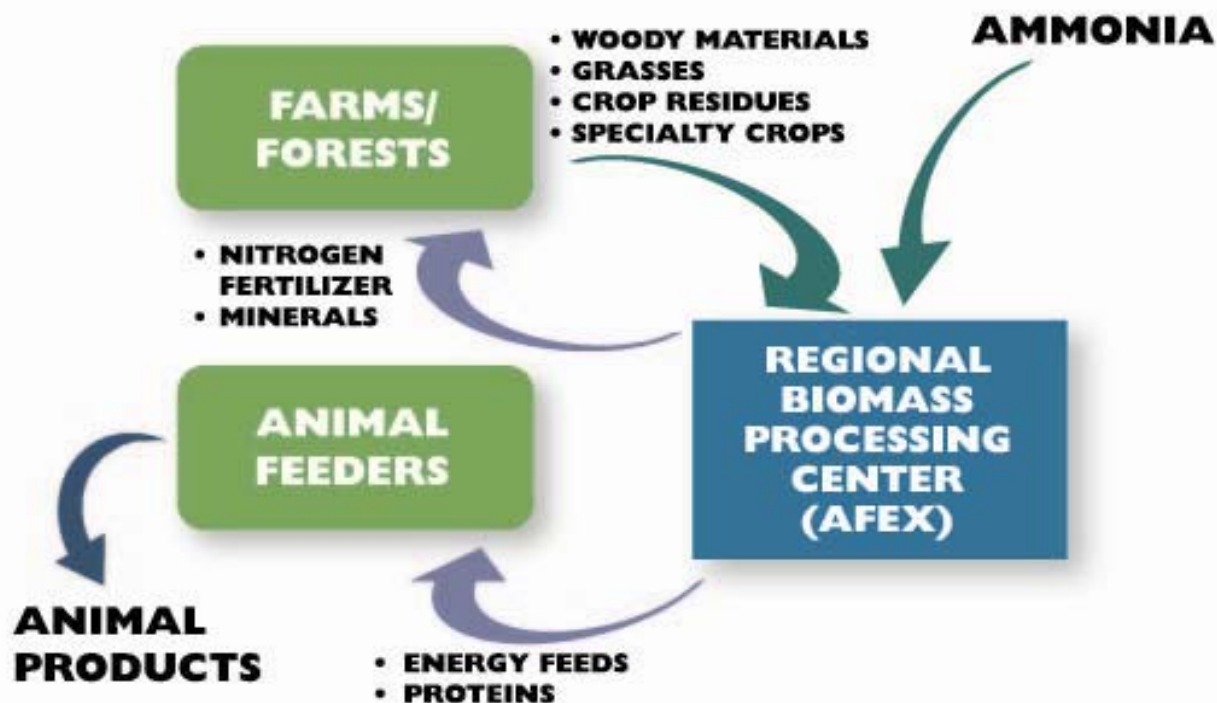
**MATERIALS
PRODUCERS**

BIOREFINERY

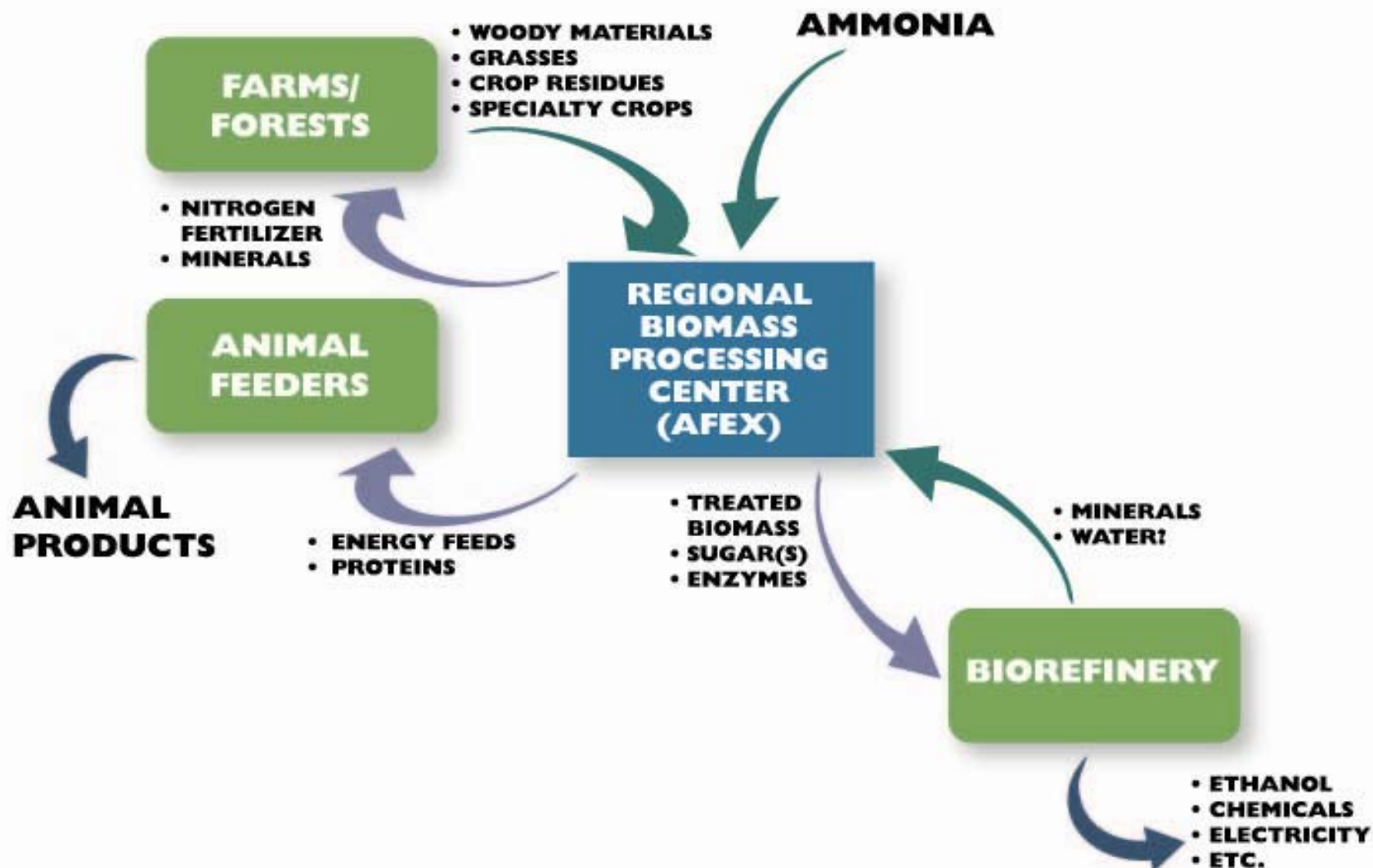
REGIONAL BIOMASS PROCESSING: SUPPLY CHAINS



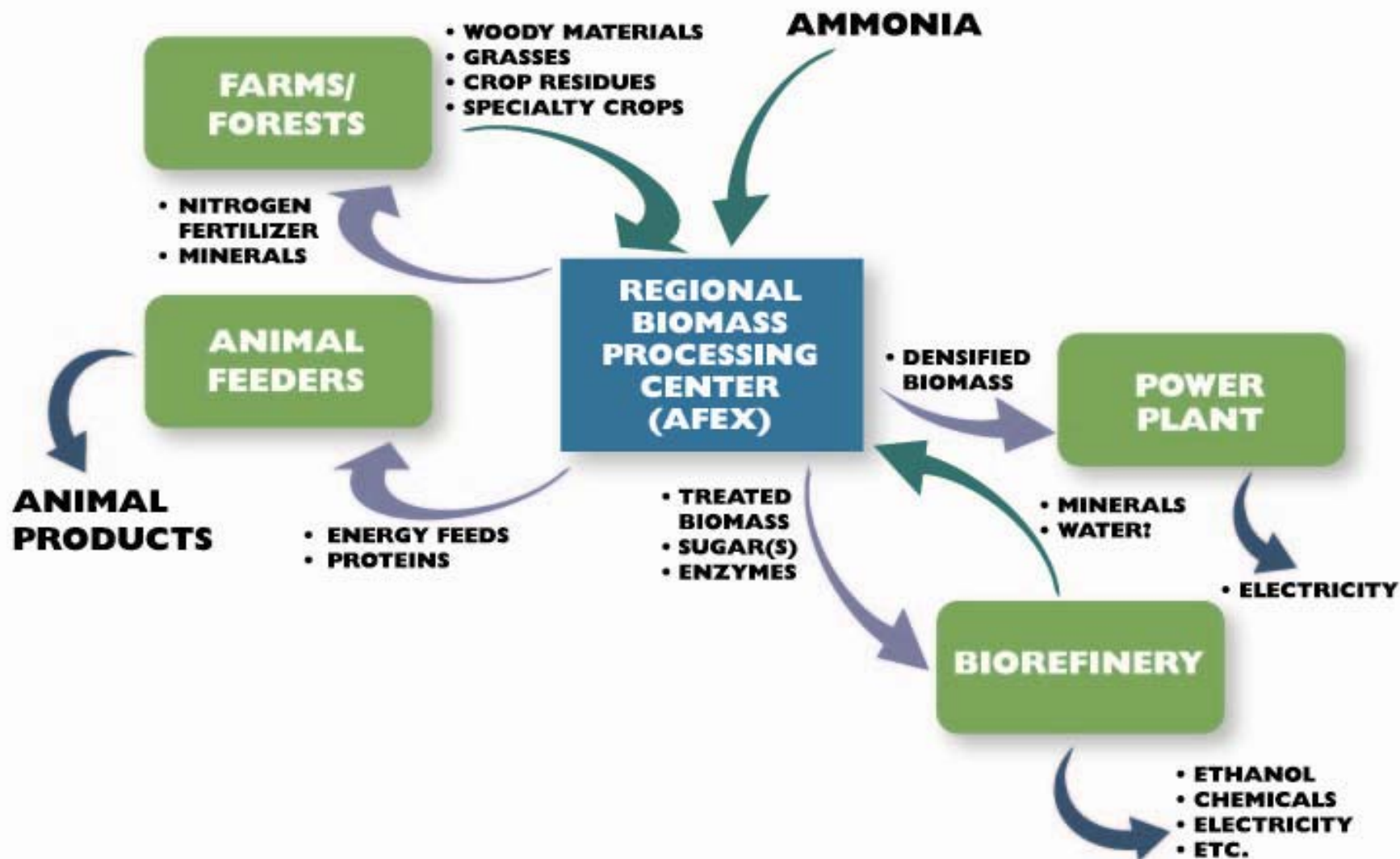
REGIONAL BIOMASS PROCESSING: SUPPLY CHAINS



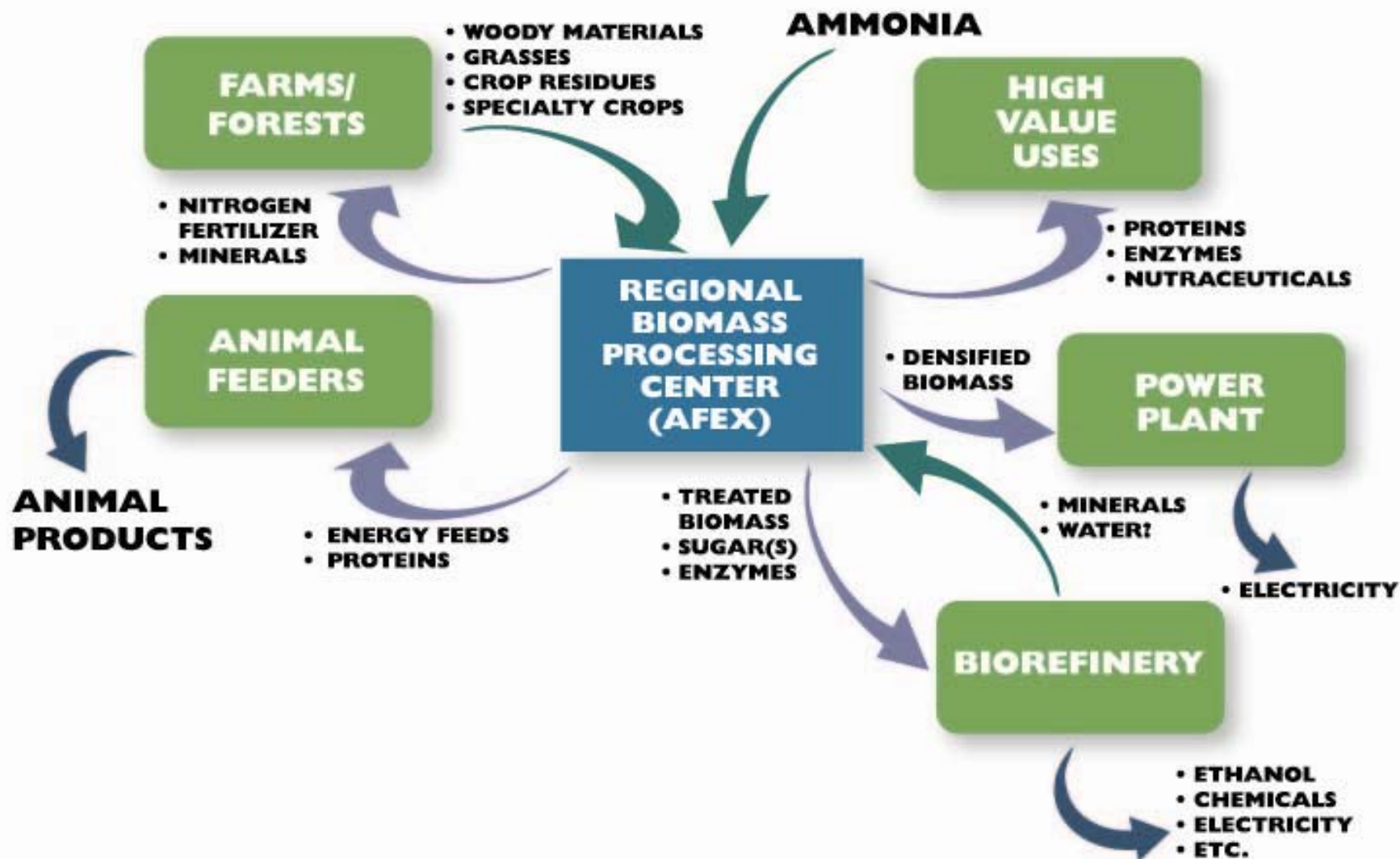
REGIONAL BIOMASS PROCESSING: SUPPLY CHAINS



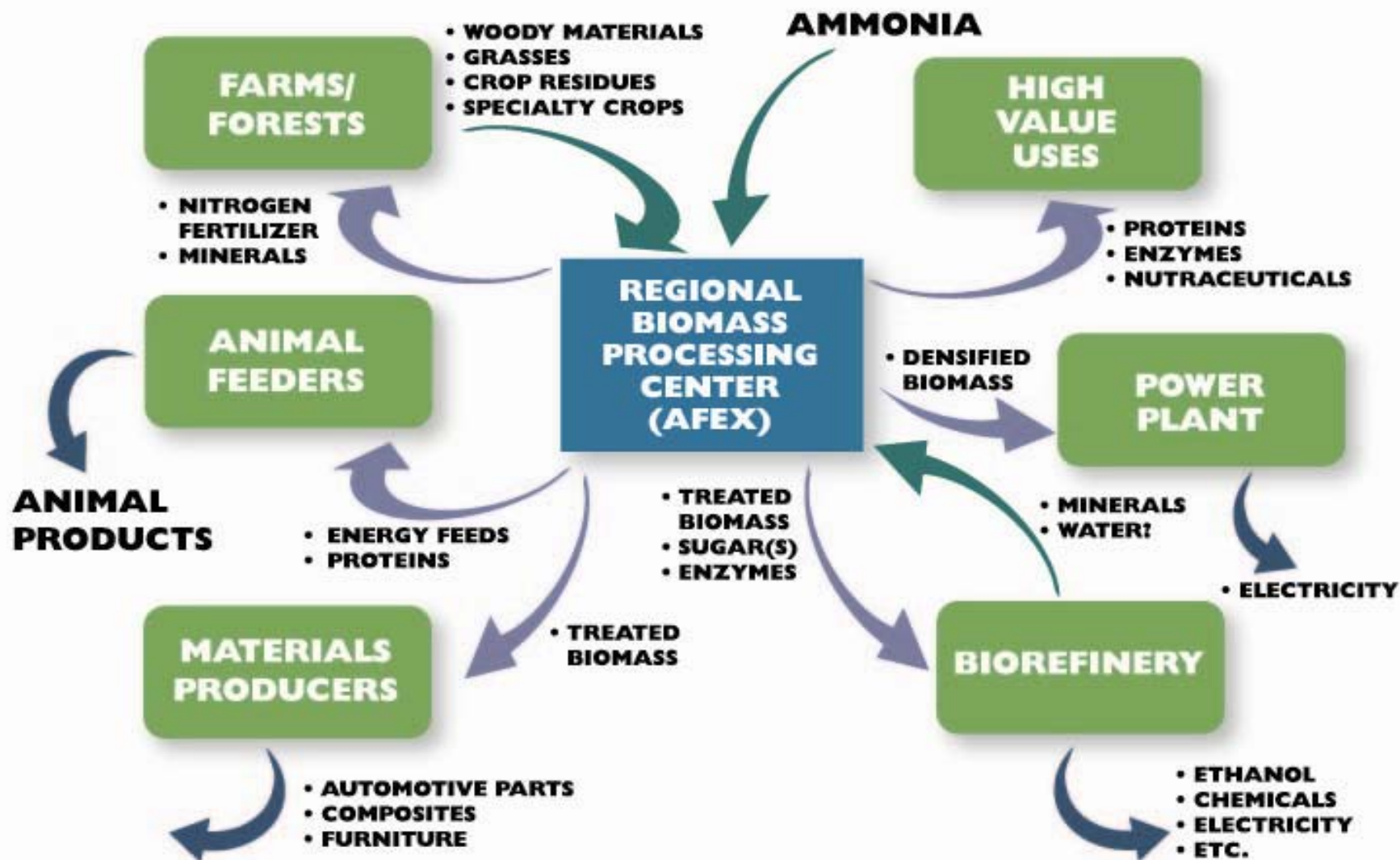
REGIONAL BIOMASS PROCESSING: SUPPLY CHAINS



REGIONAL BIOMASS PROCESSING: SUPPLY CHAINS



REGIONAL BIOMASS PROCESSING: SUPPLY CHAINS



Why We Should Explore Regional Biomass Processing Centers

- Rising corn prices negatively affect animal feeding operations— *provide feed alternatives*
- Ruminant animals are well-suited to high digestibility grasses (by pretreatment)
- Develop prototype supply chains & pretreatment systems for cellulosic ethanol (and butanol and...)
- Many more states/locations can grow grass than can grow corn—more widespread benefits
- Provides processing locus for high value products (biobased composites, nutraceuticals, etc.)
- Position ourselves to export these technologies

Rebutting Some Ethanol Myths

- Ethanol has a negative “net energy”
 - Gasoline has a worse net energy & besides, the “net energy” discussion is foolish
- People will starve with large scale biofuels
 - It is much more likely that food supplies will *increase* with very large scale biofuels
- We will devastate the environment with large scale biofuels
 - Actually, environmental improvements are both possible and likely

Questions ??

